SIMPLIFIED ANALYSIS OF SHIELDING REQUIREMENTS

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1. Basic Conditions:

a) Radioactivity build-up in hot spots will be limited to allow practical personnel access times. Exposure times will be controlled to limit individual doses to below the MPD. Beam current will be restricted as required to limit beam spill power, until low spill factors are achieved, when beam current can be increased.

b) Radiation intensity during operations is proportional to spill power. Beam spills are treated as point sources, using spill power at each point. Observed intensities outside shield at AGS are used to obtain an "equivalent unit source" per kw spill power and at a nominal 1 ft. distance from source.

c) Attenuation factors due to shielding and distance are calculated for the several sizes of enclosures at NAL, for earth fill and mill-scale fill, as a function of thickness of fill in ft.

d) Radiation intensity in rem/hr is calculated as a function of fill thickness for the maximum estimated spill powers in NAL enclosures, using appropriate attenuation factors.

e) Allowable intensities outside shields are based on the MPD and probable occupancy times at the several spill sites near or far from occupied areas. These are used to determine shield thickness for the several enclosures.

f) Recommendations are made for shield thickness for components of ring enclosure. Since these are based on maximum spill powers and acceptable outside intensities, thicknesses are taken directly from the plot in d) above.

g) Calculation of resulting intensities for special cases:
1) accidental full-power spill of beam in main ring,
2) high-rise laboratory building,
3) equipment gallery above booster ring,
4) conditions for 400 GeV operation.

2. Maximum Power Limitation in Spills:

In an earlier study (Control of Radiation, M. S. Livingston, 12/7/67) the induced radioactivity levels expected 1 hr after shut-off are given for various spill powers, based on observed Raa intensities at the AGS. With a 10 kw spill (2% of design beam power) the ambient Raa will be 25 rem/hr, with much higher values near hot components. This is 5 times the maximum allowed for unshielded personnel access with practical exposure times, and will require use of shielded vehicles. So <u>10 kw</u> is taken as the maximum allowable spill power in hot areas. At the booster ejection region a maximum of <u>5 kw</u> (20% spill) is taken. In the quiet sectors of the main ring, where spills will occur only by accident or mistuning, the maximum spill power is taken as <u>1 kw</u> (0.2% spill).

3. Equivalent Source Intensity:

Radiation intensity outside the shield at the AGS during operation at 4×10^{11} p/sec, 30 GeV, 90% on target (1.9 kw) was observed to be 1.0 rem/hr; the unit intensity was 0.52 rem/hr/kw. The shield consisted of 1 ft concrete ($d = 2.5$ g/cm^3) and 10 ft sand ($d = 1.8$ g/cm^3), or a total of 638 g/cm^2, with a ceiling height 12 ft above the beam. The equivalent unit point source at 1 ft from the target is

$$I_o = P_o R^2 e^{x/\lambda} = 0.52 \times (23)^2 \times e^{638/130} = \underline{3.70 \times 10^4 \text{ rem/hr/kw}}$$
$$\underline{@ \text{ 1 ft}}.$$

The attenuation coefficient, $\lambda = 130$ g/cm^2, is that observed at CERN for nucleonic showers with good geometry (point source). Additional shielding around the AGS source due to magnet iron or local shielding is neglected; to be equivalent at NAL, such local shielding should equal or exceed that at the AGS.

4. Shielding Factors for Enclosures at NAL, as a function of thickness t (ft):

Use: $F = \frac{1}{R^2} e^{-x/\lambda}$. R = total distance outside shield; x_o = concrete roof shielding in g/cm^2; x = shielding fill thickness t in g/cm^2; $\lambda = 130\ g/cm^2$.
Density of earth fill taken as $d = 1.8\ g/cm^3 = 112\ lb/ft^3$.

Location:	Encl. height: (ft)	roof: thick: (ft)	Dist: R: (ft)	Shield: $x_o + x$: (g/cm^2)	Fig. 1 Curve:
Main Ring:					
Mag. sectors:	5	1	6 + t	76 + 55 t	A
St. sections: (beam scrapers)	6	1	7 + t	76 + 55 t	B
Eject. straight	17	2	19 + t	152 + 55 t	C
Booster: (earth)	6	1	7 + t	76 + 55 t	B
(Mill scale): $(d = 4.2\ g/cm^3)$	6	1	7 + t	76 + 128 t	D

5. Intensity Outside Shields, as function of spill power and thickness:

Use: $I = I_o P F$. $I_o = 3.70 \times 10^4$ rem/hr/kw @ 1 ft. Use P = 10, 5, 1 kw.

Use shielding factors F plotted in Fig. 1. Results are plotted in Fig. 2.

Location:	Power, P: (kw)	Shield. Factor:	Fig. 2 Curve:
Main Ring:			
Mag. Sectors: far:	1.0	Fig. 1, Curve A	c
near:	1.0	Fig. 1, Curve A	c
St. sections: (beam scrapers)	10.0	Fig. 1, Curve B	a
Eject. straight:	10.0	Fig. 1, Curve C	d
Booster: (earth)	5.0	Fig. 1, Curve B	b
(mill scale):	5.0	Fig. 1, Curve D	e
Cool: (earth):	1.0	Fig. 1, Curve B	c
(mill scale):	1.0	Fig. 1, Curve D	f

6. Recommendations: The allowable intensities outside the shields differ, depending on distance from occupied areas. Three intensity levels are chosen: 1) 25 mrem/hr above shield far from occupied areas, 2) 10 mrem/hr above shield near (over 100 ft) occupied areas, and 3) 2.5 mrem/hr just outside the shield (i.e. the equipment gallery above the booster). These limits are indicated on the appropriate curves of Fig. 2, and determine the thickness required in each case. These results are summarized in the recommendations below:

Location:	Outside Inten: (mrem/hr)	Fig.2 Curve:	Shield Thickness: (ft)
Main Ring, far:	25.	c	18.
near:	10.	c	20.
St.sects, far:	25.	a	22.
St.sects, near:	10.	a	24.
Eject.sect, near:	10.	d	20.
Booster, hot areas:	2.5	b	25.
cool areas:	2.5	c	22.
Booster, (mill scale): hot areas:	2.5	e	12.
cool areas:	2.5	f	10.5

7. Analysis of Special Situations:

a) Accidental spill of beam at a single point in the main ring:
Assume the full beam (5×10^{13} p/pulse) at 200 GeV energy is spilled. The equivalent source intensity at full power (480 kw) is $I_m = 1.77 \times 10^7$ rem/hr @ 1 ft. Minimum shield thickness (Fig. 2) is 18 ft of earth over the main ring, for which the shielding factor $F = 5.0 \times 10^{-7}$ (Fig. 1,A). Intensity outside shield, $I = I_m F = 8.8$ rem/hr $= 2.45 \times 10^{-3}$ rem/sec. The dose from a single pulse (4 sec cycle) is $D = 4\ I = 1.0 \times 10^{-2}$ rem. This is 0.3 % of the MPD for 3 months or equivalent to 4 hrs exposure at 1 MPD for radiation workers. It is not a significant hazard.

b) Intensity at high-rise office and laboratory building: This building is located 250 ft from the main ring or 300 ft slant distance, opposite a "near" region where maximum intensity outside the shield will be $I_1 =$ 10 mrem/hr. Attenuation due to distance from source is $I_2 = (\frac{24}{300})^2\ I_1 = 6.4 \times 10^{-2}$ mrem/hr. This is 25% of the MPD for nonradiation workers of the general public. Additional local shielding around hot spots is neglected. Skyshine is also neglected but will not change I_2 enough to be a hazard.

c) Equipment gallery above the booster: Maximum allowable spill at the booster will produce intensities in the gallery of 2.5 mrem/hr, or 1 MPD for radiation workers. Occupancy times can be limited to a fraction of 40 hr/wk so accumulated does will be a fraction of 1 MPD.

d) 400-GeV operation: The design average beam current at 400 GeV is the same as at 200 GeV, so beam power is doubled. By the time this is achieved beam spill fractions should be reduced at least to half by development. So the same beam spill powers will apply and shielding will be adequate.

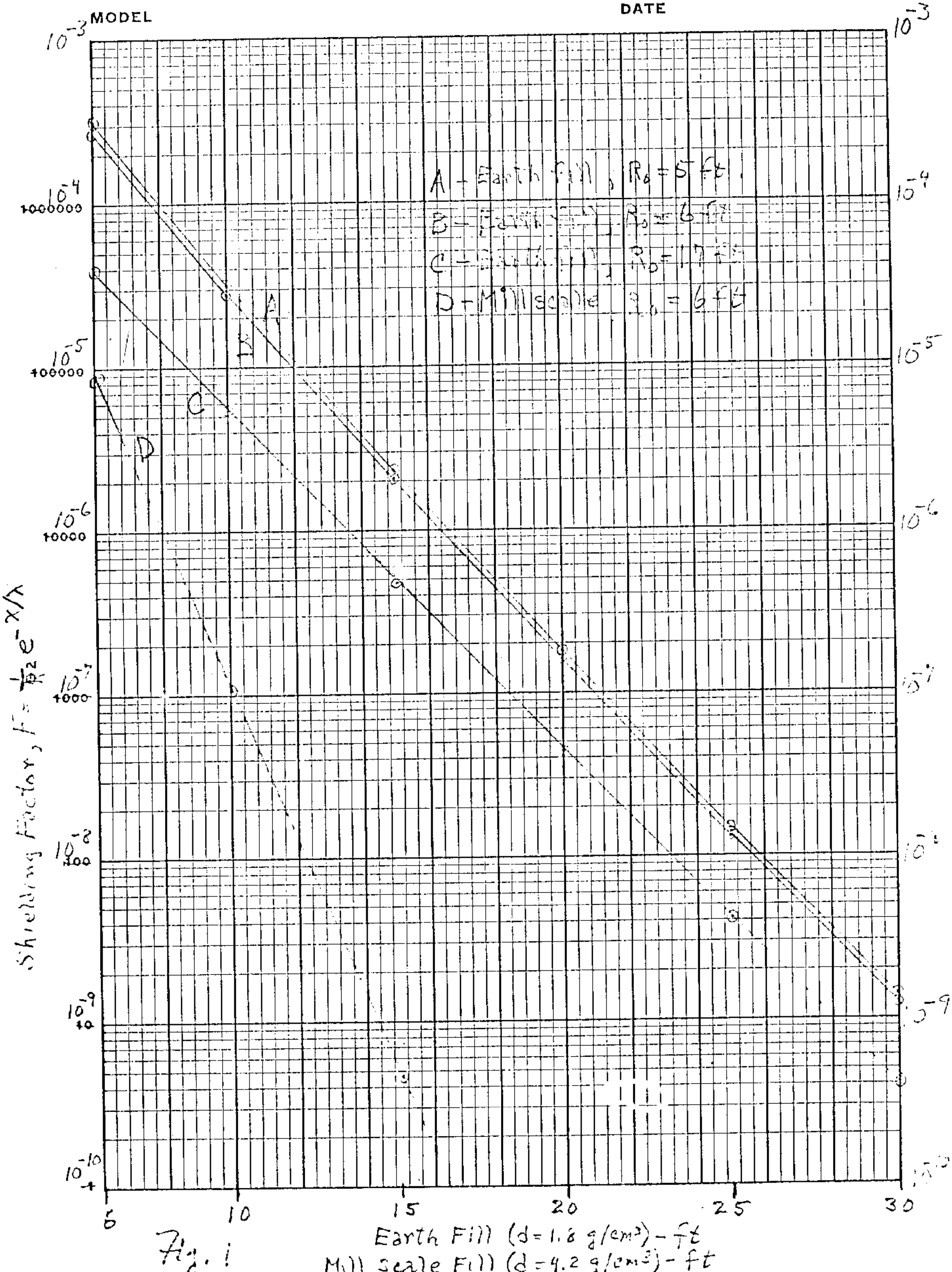
MODEL
DATE
A - Earth fill, R_0 = 5 ft
B - R_0 = 6 ft
C - R_0 = 17 ft
D - Mill scale R_0 = 6 ft
Shielding Factor, $F = \frac{1}{R_0^2} e^{-x/\lambda}$
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
5
10
15
20
25
30
Earth Fill ($d = 1.8\ g/cm^3$) - ft
Mill scale Fill ($d = 4.2\ g/cm^3$) - ft

Fig. 1

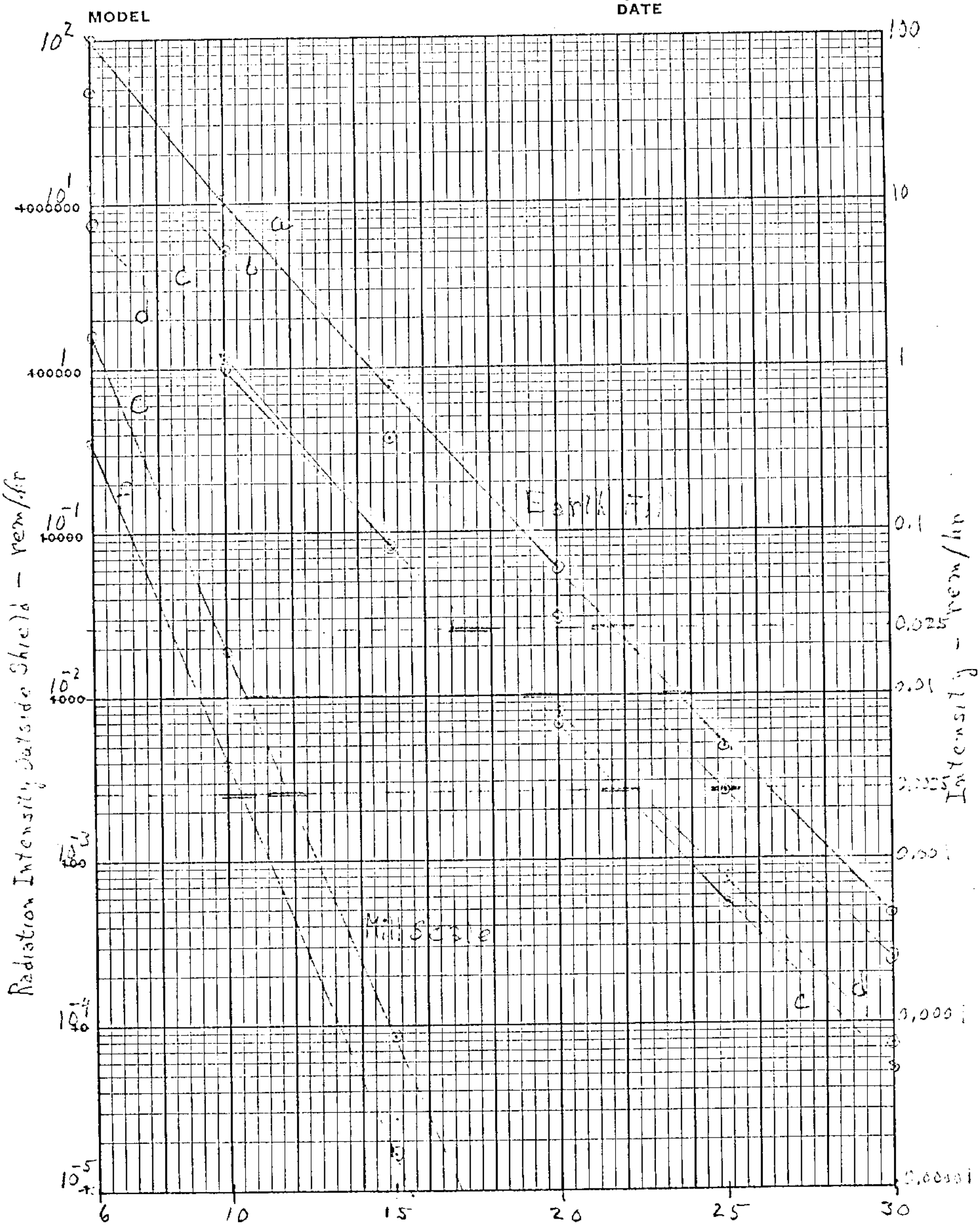

Fig. 2. Fill Thickness - ft.